Remote Automatic Material On-Line Sensor (CPS# 1254)

Goal: Develop low cost NMR sensor for analysis of industrial materials (e.g. wood chip moisture content)

Challenge: NMR can provide unique information about material properties, but cost and ruggedness problems have limited use.

Benefits: Improved accuracy of measurements allows for more efficient process control.

FY05 Activities: Complete work on prototype system and perform beta testing at Paprican

Participants: Quantum Magnetics, Physics Solutions, Paprican

Remote Automatic Material On-Line Sensor (CPS# 1254)

Barrier-Pathway Approach

Barriers

- Low energy efficiency due to inaccurate material property measurements
- NMR "too expensive" for most industrial applications

Pathways

- Develop data analysis protocol
- Develop components for low cost NMR – electronics and *Magnet*
- Work with Paprican to develop control algorithms

Critical Metrics

- Moisture content accurate to 1% at 50% MC in less than 2 seconds

Benefits (est.)	**2020**
Energy Savings	5 trillion Btu
Cost Savings	$50 million

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Progress to date (FY00 to FY03)
  - Demonstrated NMR capable of measuring MC to ±1% at 50% MC in about 1 minute for several hardwood and softwood species
    - Capable of ±2% accuracy with Pine at 140% MC (note MC is defined as weight of moisture divided by weight of dry wood)
    - Accuracy independent of configuration of wood (solid, wood chips, sawdust)
    - Can use UCB/LBNL developed protocol for rain/moisture and ice/fiber discrimination
    - Existing technology accurate over MC range of 5-25%
  - Magnet designed and fabricated
    - Designed for low cost of manufacture
  - RF coil designed and fabricated, major electronic components acquired

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Progress to date (FY04)
  - Development of novel Low Noise Amplifier (LNA)
    - Development work shared with NQR land mine detection programs and NQR explosives detection program
    - No commercially available meets requirements
      - Very low input noise (noise temperature less than 20ºK)
      - Input impedance << optimum source impedance
      - High dynamic range (important for NQR landmine detection)
      - Rapid recovery from transmit pulse
        - » NQR - 4KV to 10's of nV in 100 micro-seconds
        - » NMR – 700V to 100 nV in 20 micro-seconds
    - Provides for improved sensitivity and measurement accuracy

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Basis for LNA requirements
  - Measurement accuracy improves with increasing Signal to Noise Ratio (SNR)
  - Several methods for improving SNR
    - Increase measured sample size (increase cost)
    - Signal averaging (increased measurement time)
    - Use higher magnetic field (increase cost, magnet weight and other complications)
    - Take steps to lower noise
      - Accomplished with new LNA
  - Don’t forget recovery time

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Noise reduction techniques
  - Have three sources of noise
    - Input noise of LNA
    - Johnson noise of RF coil
    - Noise coupled from “outside world”
  - LNA input noise minimized by proper device selection
    - JFET’s can have noise temps of ~1°K at “room temperature”
  - RF coil Johnson noise can be reduced by reducing equivalent series resistance (esr) of coil and capacitors (increases ‘Q’)
    - Noise voltage is proportional to the square root of resistance times temperature
  - “Outside world” noise minimized by shielding

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Problem: Lowering ESR increases recovery time
  - May also result in system bandwidth being less than signal bandwidth
  - Requirements of Solid State NMR limit recovery time
  - Time constant = $2 \times Q/\omega$
- Solution: Reduce Q by increasing loading of coil by LNA input impedance
  - Lower equivalent parallel resistance (EPR)
    - $EPR = ESR \times (Q^2 + 1)$
  - Input of LNA equivalent to a resistor at 10 to 20ºK
  - System noise largely dominated by Johnson noise of coil

Remote Automatic Material On-Line Sensor (CPS# 1254)

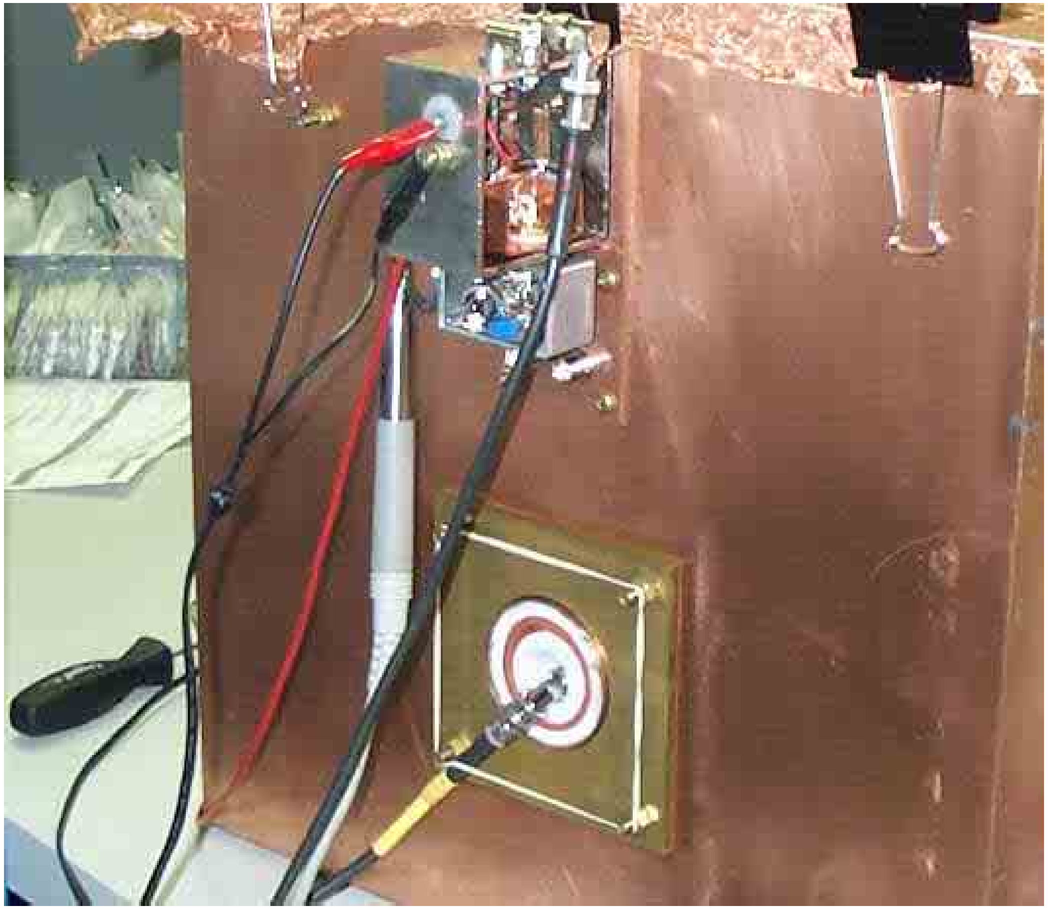
- LNA principle of operation
  - Use large value feedback resistor between inverting input and output of a low noise gain block
  - Gain block has very high input impedance (JFET)
  - Input impedance = R_{fb} / Gain
  - Feedback resistor noise voltage is absorbed by gain block
  - Feedback resistor current noise is that of high value resistor, I.e. much less than that of resistor equivalent to input impedance
  - Source impedance for optimum noise performance is much higher than input impedance
    - Parallel R-L-C circuit has high impedance at resonance
  - All of this has been done before, the hard part is making this work with a very short recovery time.
    - Use proprietary techniques

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Problems encountered
  - Noise much higher than predicted by SPICE simulations
    - Had problems with one lot of JFET's
    - Re-designed input protection network
  - Stability – gain block has very large gain bandwidth product (~6 GHz)
    - Amplifier interacts with high frequency modes of RF coil
    - "Oscillators won't, amplifiers will"
  - Ground loops (what is ground?)
  - Interaction of protection scheme
- LNA almost ready as of June 17, 2004
  - Stability problems appear to have been solved, noise looks good
  - Next step is to optimize recovery performance

Remote Automatic Material On-Line Sensor (CPS# 1254)

Low Noise Amplifier undergoing testing with RF Coil and shielding enclosure



Remote Automatic Material On-Line Sensor (CPS# 1254)

- Plans for FY05
  - Integrate LNA with balance of system
  - Final testing and assembly
  - Beta test system at Paprican (Vancouver, BC)
  - Write final report
  - Start work on commercialization

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Commercialization Plans (woodchips)
  - QM and Paprican to cooperate on developing system to meet the needs of the Paper and Pulp industry
  - QM to retain rights on NMR technology
  - Paprican to retain rights on application to the paper and pulp industry
  - InnoVec (also an InVision Technologies company) to manufacture systems
- Commercialization Plans (lumber)
  - QM to work with InnoVec to meet the needs of the lumber industry (both hardwood and softwood)
  - Manufacturing to be done by InnoVec

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Commercialization Plan

On March 15, GE and InVision management reached an agreement for GE to buy InVision Technologies pending shareholder and regulatory approval.

It is expected that QM will continue with current contract work after the acquisition.

Remote Automatic Material On-Line Sensor (CPS# 1254)

- Commercialization Plan – other applications
  - We have demonstrated the ability to measure the hydrogen content of quicklime (CaO)
    - Potential applications in cement, glass and steel industry
  - Wood moisture content is done by measuring ratio of moisture to fiber, can use same data to determine fiber content
    - Paper recyclers interested in fiber content
    - Biomass fuel users interested in fiber (cellulose) content

Remote Automatic Material On-Line Sensor (CPS# 1254)

Related work

A small magnet designed for evaluating citrus fruit in the field – general design could be used for materials analysis